**Astr 191 – Homework Problems (T. Yaqoob)**

## Clusters and the Cosmic X-ray Background

- (i) For a particular set of clusters the X-ray luminosity is found to be proportional to $T^{2.6}$, where $T$ is the X-ray temperature. What is the temperature of a cluster whose luminosity is four times that of another cluster, whose temperature is $kT = 3$ keV?
- (ii) A particular cluster of galaxies has a gravitating or characteristic radius, $R_G = 2$ Mpc and a radial velocity disperion (i.e. one-dimensional dispersion) of $\sigma_r = 1500$ km s$^{-1}$.

  (a) Estimate the virial mass.
  (b) Show that the escape velocity of a galaxy at $R_G$ is $v_{\rm esc} = \sqrt{6\sigma_r}$.
- (iii) Explain why type 1 quasars *cannot* account for most of the hard cosmic X-ray background. What were the principal technological advances necessary to discover what kind of sources *do* constitute the hard X-ray background?

## Cosmology

- (ii) Explain the principal characteristics of the three types of Universe resulting from the solution of Einstein's field equations for a simple expanding Universe, with zero cosmological constant.
- (iii) Calculate the critical density of the Universe, $\rho_c = 3H_0^2/8\pi G$, in units of g cm$^{-3}$, using $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$.
- (iv) The energy density of the Cosmic Microwave Background, $u_{\rm CMB}$, at the current epoch is 0.26 eV cm$^{-3}$. Convert this to an equivalent mass density in units of $g$ cm$^{-3}$ and calculate the ratio of the CMB radiation density to the critical density. Can the CMB close the Universe?
- (v) What is the role of inflation in the Big Bang theory?